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AIR FORCE RESEARCH LABORATORY

Tactile Cueing for Target Acquisition and Identification

Richard A. McKinley

Air Force Research Laboratory

Jennie Gallimore
Candace Lanning
Cathy Simmons

Human Factors Engineering Department
Wright State University
Dayton, Ohio

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14. ABSTRACT

Objective: Modern aircraft place great emphasis on visually presenting information to the pilot. To reduce strain on the visual system, other modalities should be utilized. Preliminary research has shown that tactile displays may provide an effective means of communication; however, more research is needed in this area. To refine tactile displays, this study was designed to optimize resolution and methods of coding target information to the user. Methods: Nineteen subjects were tasked with visually acquiring targets within a 3-D virtual flight environment. Resolution of the tactile display, method of coding tactile information, and the method pf presenting elevation information were studied. Results: Subjects were divided into video game experienced (VGP) subjects and non-video game (NVGP) experienced subjects. VGPs showed a significantly lower target acquisition time with the 12-tactor (high) resolution level. The NVGP group exhibited the shortest target acquisition time with the 8-tactor (middle) resolution. In addition, the NVGPs showed a significantly lower acquisition time when the type of target was not coded into a specific pattern. Conclusions: In general, it was found that video game players performed better with the highest level of tactile resolution, while non-video game players performed better with simpler pattern and a lower resolution display.

15. SUBJECT TERMS

Tactile; target acquisition; visual performance

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Tactile Cueing for Target Acquisition and Identification

Andy McKinley
Biomedical Engineer
AFRL/HEPG

Jennie Gallimore, Ph.D.
Candace Lanning
Cathy Simmons
Wright State University

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My name is Andy McKinley and welcome to the presentation entitled, "Tactile Cueing for Target Acquisition and Identification." I would like to acknowledge Dr. Jennie Gallimore for her valuable guidance on this project and my other coauthors for their contribution to data collection and the final report.

Background

- **Most information displayed visually in cockpit – can lead to over saturation of this modality**
  - **Other modalities of presenting info. (such as tactile) should be explored**
- **Sense of touch can provide large amount of info.**
  - **has 10,000 parallel channels capable of responding to stimulus interruptions as short as 10 ms (Cholewiak & Collins, 1991), (Sherrick & Cholewiak 1986)**

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This research was conducted because currently, almost all information in aircraft cockpits is displayed to the pilot visually. Currently, more and more information is being crammed into already limited real estate. As a consequence, many visual displays are becoming menu based or multifunction which forces the pilot to push several buttons to find the information that he/she needs. In addition, the visual system is prone to oversaturated and attention narrowing. In the high workload flight environment, this can cause the pilot to negate instrument checks or to miss critical information. Thus, other modalities of presenting information should be investigated. The sense of touch was used in this study due to the fact that it is capable of providing a large amount of information. It has 10,000 parallel channels that are capable of responding to stimulus interruptions as short as 10ms.

Background

- 6 different tactile receptors that have been identified and characterized (Cholewiak & Collins, 1991), (Cholewiak, 1999
  - two housed in hairy skin
  - two only found in hairless (glabrous) skin
  - two found in both
- These receptors differ in adapting rate, receptive field size, sensitive frequency range, and the sensation that they evoke (Cholewiak & Collins, 1991), (Sherrick & Cholewiak 1986), (Wainstein 1968)
- Example: Pacinian corpuscles create sensation of vibration/tickle; Ruffini endings provide sensations of stretch, shear, and tension

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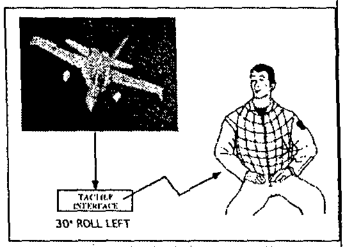
There are 6 different tactile receptors that have been identified and the are not found in all areas of the skin. For example, two are found in only hairy skin, two others are only found in hairless skin, and two can be found in both. These receptors differ in adapting rate, receptive field size, sensitive frequency range, and the sensation that they evoke. For example, Pacinian corpuscles create the sensation of vibration/tickle; Ruffini endings provide sensations of stretch, shear, and tension.

Background

- **Tactile vests:**
- **Tactile Situational Awareness System (TSAS)– Navy (McGrath, et al. 2004)**
  - **Provides spatial awareness information to pilots**
  - **Accepts data from various sensors and displays this information via vibrators or tactors integrated into flight gear**
  - **24 tactor array (8 columns and 3 rows around the torso) and 4 electromagnetic tactors (2 on the shoulder and 2 on the ventral thigh area).**



Tactile displays are not new technology. The navy has been developing and testing a tactile display called the Tactile Situational System, or TSAS. The purpose of this vest is to provide information about the orientation of the aircraft to the pilot. The system accepts data from onboard sensors and then displays this information through vibrating tactors on the torso. The current configuration is a 24-tactor array (8 columns and 3 rows around the torso). It also contains 4 strong electromagnetic tactors – 2 on the seat and two on the shoulders. A photo of the vest can be seen at the bottom of this slide.

Background

- Pilots demonstrated improved control of aircraft during complex flight conditions with TSAS (McGrath et. al. 2004)
- Shown to increase Situation Awareness (SA) (Rupert et. Al. 1996)
  - This provides opportunity to devote more time to other instruments and systems when flying in task saturated conditions
- Reduced pilot workload
- Shown to aid helicopter pilots in hover (McGrath et. al. 2004)
  - Reduced drift
- Can provide wide variety of information (Chiasson et. Al, 2002)
  - attitude, altitude, velocity, navigation, acceleration, threat location, targets

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Some of the outcomes of TSAS research are displayed here. The navy has been able to show that pilots demonstrated improved control of the aircraft during complex conditions, increased situational awareness of the pilot, reduced workload, and aided helicopter pilots in hover by reducing drift. In addition, tactile displays are capable of displaying a wide range of information to the pilot besides orientation information, including altitude, closure rate, velocity, acceleration, threat location, and the type of target.

Objective

Goal:

Improve methods of displaying information about target aircraft to a pilot through tactile displays on the torso

Specific Aims:

- **Determine optimal azimuth resolution of the tactile display**
- **Establish optimal method of presenting target aircraft altitude information**
- **Assess whether coding symbology to identify types of aircraft is useful and effective**

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The goal of this particular study was to improve the methods of displaying information about targets to a pilot through torso tactile displays. Specifically, this study was designed to optimize the resolution of the display in the azimuth plane, establish the optimal method of displaying aircraft altitude information, and assess whether coding symbology to identify the type of target is useful and/or effective.

Subjects

- Total of 19 subjects (12 male, 7 Female)
  - Mean Age: 28 $\pm$ 8.3 years
- All subjects met following criteria:
  - Normal or corrected vision to at least 20/40
  - Waist size between 28 and 36 inches
  - Chest size between 34 and 40 inches

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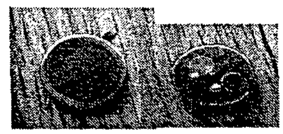
A total of 19 subjects participated in this study; 12 male, 7 female. All subjects had to meet three physical criteria to participate. Their normal or corrected vision had to be at least 20/40, waist size had to be 28 to 36 inches, and chest size had to be between 34 and 40 inches. The size requirement was due to the size limitations of the vest.

Apparatus

- Hardware:
  - Standard flight vest with 36 pager motors
    - Standard laboratory power supply or batteries
    - National Instruments 6513 high-current digital output card
  - CyVisor HMD
  - Flock of Birds head-tracker (HT)
  - Headphones (mount for HT sensor)
  - Dell Premium 330
    - Runs flight sim graphics
  - Lab computer
    - Runs tactile vest control software and displays GUI for PI



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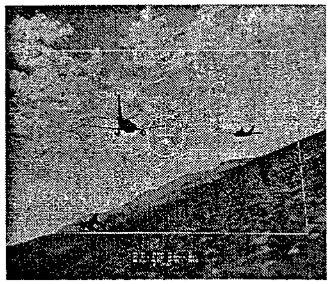
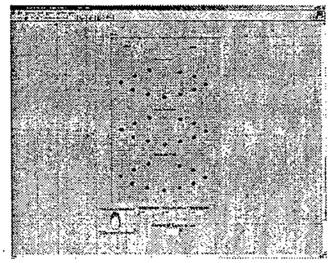
The tactile vest used in this study was a standard combat edge flight vest instrumented with 36 pager motors or tactors. The tactors were arranged in three rows and 12 columns. A CyVisor provided the visual display to the subjects, the head tracker allowed the subjects to look around in the virtual environment and two computers were used to run the visual software and collect data.

Apparatus

- Software
  - X-plane flight simulator – performance task
  - LabVIEW – controls for tactile vest





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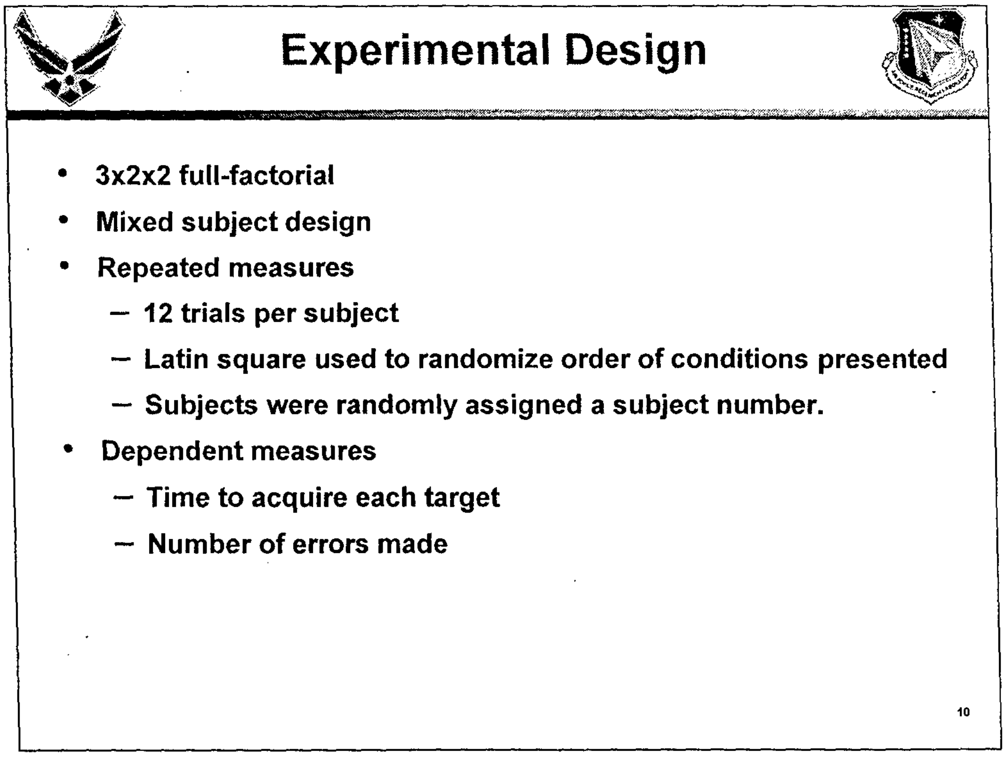
The flight simulator used was a modified version of x-plane and the tactor vest was controlled through custom software developed with LabView.



The experimental design was a repeated measures three by two by two full factorial. There were 12 data trail per subject and a Latin Square design was used to randomize the order of the treatment conditions. Subjects were randomly assigned a subject number. The dependent measures collected included the time to acquire each target and the number of errors made.

Experimental Design

- Tactor resolution (within subjects)
  - Level 1: 12 available tactors
  - Level 2: 8 available tactors
  - Level 3: 4 available tactors
- Target type coding (within subjects)
  - Level 1: single code
  - Level 2: separate code for each target type

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The first independent variable was the tactor resolution. There were three levels, which included 12, 8, and 4 tactors. The second factor was the coding for the type of target. Either a single code was presented regardless of the type of target, or a separate code was presented relating each target to a different tactile pattern. Both variables were within subjects.

Experimental Design

- Elevation presentation (between subjects)
  - Level 1: 5 elevation settings
    - ≥40° above = top tactor activated
    - 6-39° above = top and middle tactors activated
    - ±5° = middle tactor activated
    - 6-39° below = middle and lower tactors activated
    - ≥40° below = lower tactor activated
  - Level 2: 3 elevation settings
    - ≥6° = top tactor activated
    - ±5° = middle tactor activated
    - ≤6° = lower tactor activated

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The final factor was the method of elevation presentation, which was a between subjects variable. There were either 3 or five settings for the elevation of the target presentation, which are listed here. Essentially, level one provided two more degrees of resolution to the subjects than level 2.

Experimental Design

- 3 types of aircraft were displayed
- No more than 2 types of aircraft at one time
- No more than 2 of any one type at one time

	Type of Aircraft		
Condition	Enemy	Unknown	Friendly
1	1	0	2
2	1	2	0
3	2	0	1
4	2	1	0
5	0	2	1
6	0	1	2

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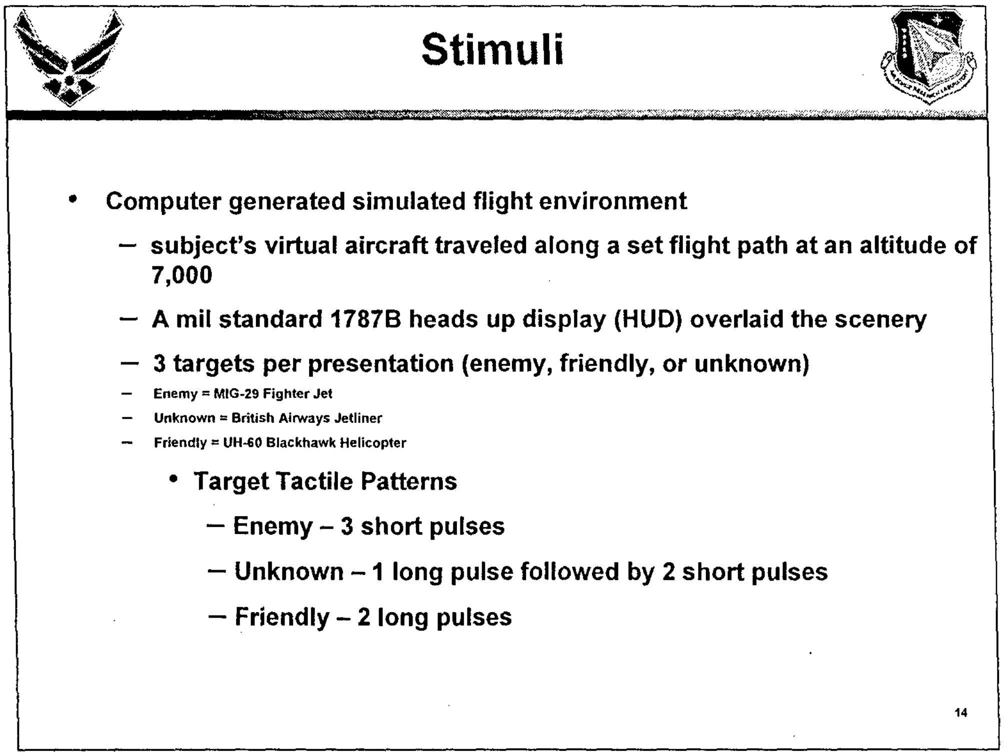
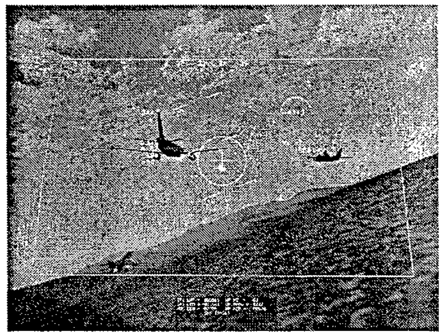
The task used in this experiment used three different types of aircraft, enemy, unknown, and friendly. The type of aircraft was randomized under the constrictions that no more than two types of aircraft could be displayed in any one trial, and no more than two of any one type of aircraft could be displayed in any one trial. For example, there could never be 3 enemy targets displayed simultaneously. This left six possible configurations which are displayed in this chart. The numbers represent the number of that particular aircraft to be displayed in that trial.



The visual stimuli consisted of a computer generated flight environment that placed the subject inside the cockpit off an F-22 fighter jet. The subjects' aircraft was held on a fixed flight path that maintained a constant altitude of 7,000 feet. In addition, a mil sttandard 1787B heads up display was overlaid on the visual scenery. Three target aircraft were presented simultaneously each trial. The enemy aircraft was a Mig-29, the unknown was a British Airways jetliner, and the friendly target was a UH-60 Blackhawk helicopter. These targets were chosen due to the fact that they were easily visually discernable. Each type of aircraft had a different tactile pattern associated with it. The pattern for the enemy aircraft was 3 short pulses, the unknown was 1 long pulse followed by 2 short pulses, and the friendly aircraft was two long pulses. These patterns were chosen to give the more dangerous aircraft a more urgent tactile pattern.

Stimuli

- **Each target's position was random (azimuth, elevation)**
  - **Distance from subject set to constant (500 ft)**
- **Targets do not move relative to subject**



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Each target's position was random in azimuth and elevation angle. The elevation angles were confined ± 70 degrees due to the fact that the head tracker failed to operate properly out of this range. In addition, the azimuth angle was confined to ± 150 degrees due to the fact that is was difficult for the subjects to twist their bodies a full 180 degrees. The targets were set at a constant distance of 500 feet from the subject so that each target would have the same visual acuity. In addition, the targets did not move relative to the subject's aircraft.

Procedure

- Training
  - Received task instructions for the training session
  - Familiarized subject with tactor placement/sensation
  - Performed the task in all 6 conditions twice
- Data Collection
  - Conducted at WSU-Russ-Room 250

During training, the subjects read written instructions for the task based on group they were assigned. The investigator then familiarized the subject with the tactor placement and sensation by exciting tactors in a variety of locations and naming that location for the subject. Each subject then performed all six conditions twice. The data collection was performed at Wright State University's Russ engineering center, room 250.

Procedure

- Task Execution
  - Set of three target aircraft (in one of 6 treatment combinations) appeared in randomized locations
  - Tasked with visually acquiring each target in the order of all enemies, all unknowns, and then all friendlies.
    - Out of sequence = Error
    - Successful acquisition: Align center "x" on HUD with center of target aircraft for two seconds.
    - Target and tactile sensation related to that aircraft disappeared after visual acquisition
    - Task timed out after 60 seconds = Error

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For each task execution, a set of three targets appeared in randomized locations. The subjects were tasked with visually acquiring the targets in the order of all enemies, all unknowns, and then all friendlies as quickly and accurately as possible. If the aircraft were acquired out of sequence, an error was reported in the data output. To successfully acquire a target, the subject had to align the center "x" on the HUD with the center of the target for two consecutive seconds. The target and the corresponding tactile cue would disappear after a successful acquisition. The task timed out after 60 seconds. IN the event this occurred, the remaining aircraft would be reported as an error.

Procedure

- Subjects completed two presentations for each treatment combination
  - Time to acquisition and error rate data were averaged across subjects for each condition
- In addition, subjects were asked how often they play video games
  - Separated into two groups
    - Video Game Players (VGPs) – Play minimum of 2-3 hours per week
    - Non-Video Game Players (NVGPs) – Never play

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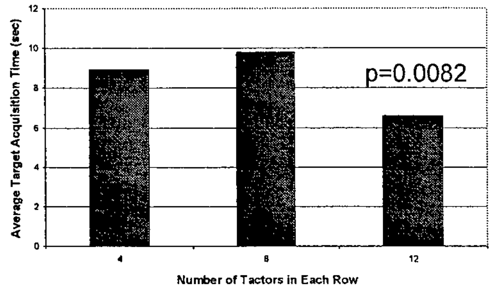
Subjects completed two presentations for each treatment combination. The dependent measures recorded in the data file were the time to acquistion for each of the targets and the number of errors for each trial. These data were averaged across subjects for each condition. Following the data collection, subjects were asked how often they play video games. Based on their responses, they were separated into two groups: Video Game Players and Non-Video game Players. Video game players played an average of two-three hours per week, while non-video game players did not play at all.

Results

- Visual Acquisition Time (VGPs)
  - Averaged across all three targets for each presentation of the task
  - Significant main effect of azimuth resolution on Acquisition Time
  - Tukey's test used
    - Times were significantly shorter for the 12 tactor treatment level
    - Azimuth p=0.0082
- Error Rate
  - No significant effects on Error Rate



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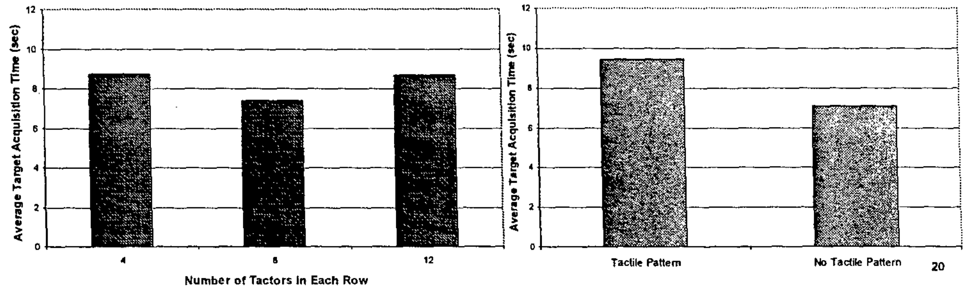
This slide discusses the results for the video game player group. The visual acquisition time was averaged across all three targets for each presentation of the task. The was a statistically significant main effect of azimuth resolution on acquisition time. Tukey's test was then employed to determine the resolution that produced the lowest acquisition time. The acquisition time for the 12 tactor condition was significantly less than for the 8 or 4 tactor resolution. The p-value was 0.0082.

Results

- Visual Acquisition Time (NVGPs)
  - Averaged across all three targets for each presentation of the task
  - Significant main effect of azimuth resolution on Acquisition Time
  - Tukey's test used
    - Times were significantly shorter for the 8 tactor treatment level
    - Azimuth p=0.0081
- Error Rate
  - Significant main effect of pattern on Error Rate
  - Tukey's test used
    - Errors were significantly greater for the "No Tactile Pattern" level
    - Azimuth p=0.0066



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The results for the non-video game player group were much different than the results for the video game player group. The data was averaged as before and again, the azimuth resolution showed a significant main effect on acquisition time. Tukey's test showed that the acquisition times were significantly shorter for the 8-tactor resolution (p-value of 0.0081). In addition, there was a significant effect of tactile pattern on the error rate. The condition in which a different tactile pattern was NOT administered corresponding to the different target types produced fewer errors than the condition where the tactile patterns indicating the type of target were given.

Discussion

- 12 tactors in the azimuth plane produced better performance (lower acquisition time) in visual target acquisition than 4 or 8 for VGPs
- 8 tactors in the azimuth plane produced better performance (lower acquisition time) in visual target acquisition than 12 or 4 for NVGPs
  - NVGPs - Errors were significantly greater for the "No Tactile Pattern" level
  - Indicates NVGPs performed better with less info.
- Although the coding pattern was not significant, it was approaching significance ($p=0.0603$)
  - Perhaps would be significant with more data

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The results showed that the video game player group performed better with the highest azimuth resolution. The non-video game players performed better with a lower azimuth tactile resolution. Neither group performed well in the 4-tactor configuration which indicates that four tactors in the azimuth plane is not adequate to provide target location information. Furthermore, the non-video game players had significantly fewer errors when given the type of aircraft was not coded with a tactile pattern. This indicates that the non-video game player group performed better with less information and less tactors. Anecdotally, many of the non-video game players found the tactile patterns overwhelming or confusing and found it difficult to interpret the signals. In addition, many of them found 12 tactors of azimuth resolution was too much, whereas many of the video game players preferred the 12-tactor arrangement.

Conclusions

- **Due to the fact that both VGPs and pilots are accustomed to responding to multiple stimuli in a high workload environment, it is likely the performance of the VGP group is more representative of a pilot's performance.**
  - **Therefore, the conclusions of this study are that 12 tactors per row (azimuth) should be the minimum requirement for torso tactile displays.**
  - **Tactile patterns were not useful to the subjects in this experiment, however different or a fewer number of patterns may lead to different results.**

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It is anticipated that the video game player group's performance is more closely linked with a pilot's performance than the non-video game players. The reason for this is that both pilots and video game players must constantly scan their environment and respond to multiple stimuli. This functional difference between the group of subjects leads to the conclusion that the results for the VGP group should be used in the design of tactile displays for pilots. Twelve tactors per row should be the minimum requirement for torso tactile displays. Although tactile patterns were not useful to the subjects in this experiment, different or a fewer number of patterns may lead to better performance.

Recommendations for Future Studies

- Compare age groups
  - Tactile symbology may be more intuitive for younger subjects based on video game experience
- Compare visual only to visual with tactile cues
- Limit azimuth angle to $\pm$130 degrees
  - limit difficulty of turning in chair
- More Realistic Simulation
  - Fly aircraft – turn aircraft, not torso
  - No acquisition of friendly aircraft

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The recommendations for the future studies are to compare age groups. It is anticipated that younger subjects may adapt better to tactile symbology due to video game experience. In addition, future studies should compare performance visual only cues to performance with tactile and visual cues. If completed under a similar design, the azimuth resolution should be limited to plus or minus 130 degrees in future studies due to difficulties experienced in turning in a stationary chair. It would also be ideal to have the subjects fly the aircraft toward the targets to acquire them as they would in the operational environment. Finally, the acquisition of friendly targets should be removed from the design. Perhaps with only two different tactile patterns, the symbology would have been more useful.

More Recommendations

- **Investigate other patterns for target coding**
- **Determine maximum number of different patterns that can be determined simultaneously**

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Other recommendations are to investigate other patterns of coding targets and to determine that maximum number of different patterns that can be identified simultaneously.

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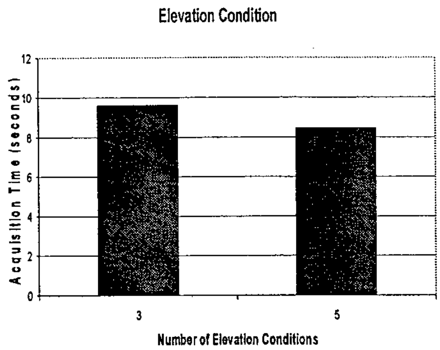
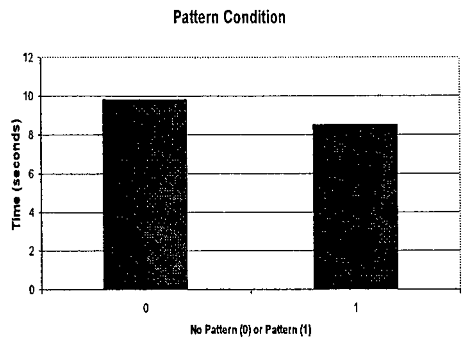
Back-up Slide





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